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1 7. BOULDERS

1.1 Introduction

1.1.1 Description of Technique

This technique relies on the strategic placement of large immobile boulders within the river system. This technique is applied to restore structural complexity and improve hydraulic diversity to homogenous sections of streams. Structural and hydraulic diversity is important to providing holding and rearing habitat for all life stages of salmonids.

Add discussion of how this activity is used in the context of restoration (not creation of habitat)

Streams with a uniform channel bottom and banks, with respect to width and depth, are a result of actions that straighten (channelize) or otherwise simplify the channel. These actions may be direct modifications of the channel (e.g. levee construction, bank hardening) or alterations of the watershed (e.g. lack of source of wood from long-time deforestation, or scour caused by splash damming, full-spanning boom cables and logs used to capture d/s floating timber, or other causes.) These actions increase water velocities, erosion, and often result in channel incision with a general reduction in hydraulic diversity. This loss of habitat diversity and complexity has a pronounced effect on the aquatic biota inhabiting that area. The combination of decreased habitat diversity and increased water velocities are especially detrimental to salmonids and their prey occupying these areas. In a section of river, devoid of hydraulic complexity, the presence of sufficient object cover (velocity breaks) is critical. The presence of shear stress gradients, where slow water velocities occur in close proximity to faster velocities, is energetically desirable for many fish species as they are able to maintain a position close to the faster, food delivering current with minimal energy expenditure. In the absence of sufficient velocity refuges, the energetic costs for fish residing there go up dramatically resulting in poorer physical condition and diminished survival.

Boulder placement has been used successfully throughout North America. Boulder placement is a common method used to create rearing habitat (Reeves et al. 1991). Fish use boulder clusters more readily than single boulders (Ward 1997). Boulder clusters have been found to be used and preferred by steelhead parr, coho fry, and cutthroat trout (Ward 1997). Ward and Slaney (1971) found that boulder groups were more successful and cost effective than gabions and rock deflectors in creating rearing habitat in the upper Keogh River, British Columbia. Three times the total salmonid standing crop was observed after improvement with boulders with densities similar to those in sections "good" rearing habitat. Canaley (1971) reported similar success in Rock Creek (Montana), where the trout population in a channelized section mitigated with large boulders quickly recovered to levels comparable to unaltered reaches. Boulders placed in Red Cap Creek, a Klamath River tributary in northern

California, increased both numbers and biomass of age one steelhead over 300 percent above those of control sections (Brock 1986). Large rock has also been used effectively to enhance salmonid habitat in several locations in the John Day River Basin in eastern Oregon (Claire 1978) and on the Green River below Fontinelle Reservoir in Wyoming (WGFD 1982).

1.1.2 Physical and Biological Effects

Placement of large boulders within the stream channel will increase the hydraulic complexity and habitat diversity of the river. The placement of large boulders (>1 cubic yard) provides diversity in bedform, water depth, and velocity. The addition of cover and velocity breaks increases microhabitat availability through these enhancements in structural and hydraulic complexity. Boulders provide energetically favorable rearing habitats and holding habitats. The microhabitats created by boulders are used by juveniles for rearing and by adults as holding habitat for feeding and during migration. Energy is conserved and feeding efficiency is maximized in the type of microhabitat created by boulders.

The presence of boulders within the stream or river system alters the hydraulic character of the stream and generally increases complexity of bedform and hydraulic diversity. Boulders may promote scour and substrate sorting. Boulders can also be used to deflect flow or create scour along streambanks and can improve aeration in higher gradient areas. Because boulders can alter the scour and depositional character of a stream, they can also lead to unanticipated deposition by creating low velocity zones. Depositional bars downstream of placed boulders are common.

1.1.3 Application of Technique

Although boulder placement has been successful in salmonid habitat creation, the risk of inadvertently causing problems should not be ignored and a hydrologist and geomorphologist should help plan projects to ensure their success (Reeves et al. 1991). While the primary intent of introducing boulders may be to create habitat, one must carefully consider the geomorphic, hydraulic, and biological ramifications associated with the introduction of large roughness elements. Foremost, there should be a geomorphic rationale for the introduction of a roughness elements such as boulders or large woody debris into a stream. Before considering the use of boulders, the project proponent should ascertain whether they are a natural component of the system. Simply using boulders to create diversity in a stream where they otherwise would not be found is not sound or appropriate restoration. For instance, boulders would not be found and should not be placed in a low gradient sand dominated reach.

The use of large woody debris to create habitat complexity is more common than the use of boulders. In the Pacific Northwest, forest practices have disrupted the supply of large woody debris to free flowing rivers. The absence of large woody debris has been well documented as a cause for reduced habitat diversity. This is not the case with boulders. For this reason, installation of woody debris more closely addresses the desired restored condition. Large woody debris also tends to be more dynamic than large rock. However, boulder placement is practical in situations where a static condition is desired and where movement of the roughness elements is undesirable. Boulders are also effective and sometimes more practical than large woody debris in mid-channel applications especially in large river systems.

The hydrologic and hydraulic characteristics of a candidate reach for boulder placement must be thoroughly understood. Boulder placement should be carefully considered in degraded or unstable stream reaches. For instance, boulders may not be appropriate in coastal conditions where extreme winter freshets and significant bedload movement are prevalent (Ward and Slaney 1997). Ultimately, the effectiveness of boulders as habitat depends heavily on sediment transport dynamics. For instance, the type habitat created when a boulder is placed in a free-flowing reach differs substantially from that created in a backwatered reach. The higher diversity of water velocities present around a boulder in a free-flowing reach create a more diverse micro-habitat. Furthermore, the substrate composition and degree of scour associated with a boulder placed in a transport reach will differ from that in a depositional reach. The presence of coarser material in the substrate provides habitat for a more diverse assemblage of organisms including multiple life stage of fish and macroinvertebrates.

Boulders are commonly used to build structures to direct channel flow, to maintain grade control, and to create scour. The use of boulders as structural channel features is further discussed in the Structures to Create and Maintain Diverse Bedform technique.

1.2 Scale

Boulder placement projects are usually intended to provide habitat benefits on a small, localized scale. Due to the cost of transporting and installing boulders, large-scale boulder placement projects are rare and usually cost prohibitive. Where appropriate, projects can be implemented in small streams and large rivers.

1.3 Risk and Uncertainty

This technique has limited risk because boulders are typically immobile. However, despite the fact that risk of boulder movement may be low there is the risk of excessive bed or bank scour, catching of debris, upstream or downstream deposition. Improperly placed boulders can lead to unanticipated scour, lateral channel migration and related backwater effects placing certain infrastructure at risk. There is also a risk to the safety of boaters associated with physical obstructions in the stream and associated alterations to channel hydraulics.

The effectiveness with which boulders create desired habitat conditions hinges on adequate evaluation of flow regimes and sediment budgets. Boulders, if improperly placed, can create unwanted and unanticipated backwater, sediment transfer (cross section occlusion and velocity effects) and scour effects. There’s also the risk of the boulders scouring a hole, falling into it, and becoming ineffective. This could take only one year or many depending on flow, substrate composition, and size and shape of the boulder.

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1.4 Data Collection and Assessment

A thorough assessment of habitat needs in subject reach should be conducted before embarking on a project involving boulder placement. Because the placement of boulders is relatively expensive and permanent, there should be a geomorphic and biologic rationale for their placement or a sound justification for their presence.

An evaluation of watershed hydrology, flow regimes, and sediment budgets is essential to achieve the desired results from a boulder project. The transport of sediment, wood, and debris must be characterized and addressed in design and installation. Site-specific hydraulics must be understood for the project to be successful and to minimize risk.

Characterization of hydrologic, hydraulic, and sediment transport conditions should include:

- Determination of channel forming discharge and flood discharges
- Flood and overbank flow profiles of existing hydrologic conditions
- Volume and gradation of sediment supply
- Hydraulics; including velocity, shear, and scour along the channel
- Characterization of sediment transport dynamics

1.5 Methods and Design

1.5.1 Site Selection

When identifying potential boulder placement sites, consideration must be given to what locations will provide the most biological benefit recognizing that the primary intent is to provide object cover and favorable holding habitat with respect to velocity. However, sites that are attractive from a biological standpoint may not be from a hydraulic standpoint (excess scour, degraded bank stability). Thus, site selection will require consideration of both biological and hydraulic appropriateness.

Biologically appropriate sites include:

- Placeholder, list of appropriate site characteristics

Hydraulically appropriate sites include:

- Placeholder, list of appropriate site characteristics

Aggradation and degradation around boulder clusters is related to the hydraulic action of the site at bankfull discharge. Because boulder clusters can cause aggradation and degradation, careful planning of the placement of boulders is needed in order to prevent stream bank erosion. Boulders should not be placed in unstable aggrading or braided channels, nor in cascade habitats which are transport reaches (Ward 1997; Montgomery 1993). Boulders should be placed in streams with a gradient equal to or less than 3%, where the slope is greater than 3%, additional planning and monitoring may be necessary. No boulders should not be placed in streams greater than 10% slope (Ward 1997;

Montgomery 1993).

1.5.2 Boulder Placement

Generally, boulders should be placed in random patterns that replicate natural stream conditions and do not substantially modify overall stream hydraulics. They should be placed to create local scour, without creating general channel scour or backwater. This can be accomplished with the use of hydraulic models that can account for the impact of the boulders on the channel cross section. Hydraulic models are detailed in the Hydraulics Appendix. The size and shape of boulders, their arrangement and their orientation, should all be based on watershed hydrology and the hydraulic conditions at the candidate reach.

The designer should carefully consider how much of bankfull channel cross-section should be blocked by boulders and the associated implications. Boulder placement and alignment must consider potential impacts under high flow because of the risk of unintended consequences (excessive bed or bank scour, catching of debris, upstream deposition). Boulders should not be allowed to block a significant portion of the channel cross-section. The top of the boulders should be below bankfull elevation, spaced one to three feet apart and clusters staggered at least one to three channels widths apart (Ward 1997; Montgomery 1993).

In terms of arrangement, boulders are better utilized by fish when placed in groups of three to five per cluster and located in riffle and glide habitat. Boulder clusters work best when placed at the bottom half of riffle habitats. Clusters should work together to compliment the stream flow and provide fish cover (Ward 1997). Recent research suggests that placement of boulders in clusters arranged in diamond and 'v' patterns increases local scouring and results in increased diversity in water depths and velocities over other arrangements. Clusters of three to seven boulders are effective when placed in a horseshoe configuration pointed upstream (Slaney 1997). Spacing between boulders should be one to three feet, increasing with stream size, and clusters staggered about one to three channel widths apart (Montgomery 1993). This configuration is most beneficial to fish and is hydraulically stable.

Installation should also account for anticipated scour. Boulders will work themselves into the streambed during flow events that mobilize channel bed materials, by falling into scour holes. Thus, boulders should be installed such that their bottom edge is at a depth greater than the anticipated depth of scour. A depth of 1.5 times the depth of scour is commonly applied and is recommended. For further discussion of scour and the computation of scour, refer to the Hydraulics Appendix.

Boulders should not be placed to form weirs (e.g. step pools), barbs, or dams, provide streambank stabilization, or other structural or armoring forms. Boulders should not obstruct fish passage under any flow conditions.

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1.5.3 Boulder Size and Shape

Generally, minimum boulder size is of greater concern than maximum boulder size. Boulders that are too small will wash away, or simply fall into scour holes and become buried or ineffective. Boulders should be sized to be immobile at all anticipated flow events, and large enough that they will not fall into scour holes. This can be accomplished by sizing boulders such that the bottom third of the boulder is installed to approximately 1.5 times the anticipated depth of scour. Sizing of boulders can be accomplished using tractive force computations and riprap sizing computations, which are detailed in the Hydraulic Appendix.

Angular boulders are generally more stable than rounded boulders and most computations assume that the particles (boulders) are angular. Rounded boulders roll more easily, and may not stay in place. Placeholder – state what the ratio is of rounded to angular rock size, how much bigger a rounded rock needs to be than angular when using common rock size equations. Angular boulders may also provide greater hydraulic complexity than rounded rock. The use of angular or rounded boulders can have significant aesthetic impact however, particularly in systems that are dominated by one or the other.

1.6 Project Implementation

1.6.1 Permitting

Permitting channel modification projects will be very site- and project-specific. Channel modification invariably involves physical disturbance of the channel, which disrupts habitat and water quality at the site and downstream. A general discussion of permitting requirements is included in the introduction to Chapter 5 of this document.

1.6.2 Construction

Two types of equipment are typically used for transporting the boulders from the stockpile locations and placing them in the river: a hydraulic excavator with a 1-cubic yard bucket fitted with a thumb; and a helicopter with a 1-ton transport capacity. A hydraulic excavator would be appropriate to use if there are many available access points and the excavator can easily move up and down the river channel. Equipment used for placement will virtually never be allowed to operate in the river or stream but will be restricted to the bank where riparian vegetation will be temporarily destroyed-- that may or may not be acceptable. Consequently, a long arm excavator (60 feet) reach will almost always be needed to reach over vegetation and put the rock out in the stream channel. If access is limited or the flow is too high to operate an excavator, then a helicopter could be used to transport the boulders from the stockpile and place them in the river.

Construction should be conducted during a period where impacts to critical life cycles, such as spawning or migration, are avoided and when dewatering for construction is possible. Low-flow conditions are ideal for the placement of boulders and may be essential for dewatering efforts. Dewatering eases installation and prevents siltation of the stream during construction. In-stream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*). Further discussion of construction timing and dewatering can be found in Appendix M, *Construction Considerations*.

1.6.3 Cost Estimation

The costs associated with boulder placement depend on the availability of boulders, distance from source of material to the site, access to the river, and the type of equipment used. Access to the river may be limited to certain locations. Boulders are often delivered to access points and stockpiled. Boulders may be locally available within the general vicinity of the areas requiring treatment. The cost to deliver boulders to the stockpile locations is estimated to be about $35.00 per boulder (based on a 3-ft diameter).

A hydraulic excavator (with operator) will cost about $100 to $150 per hour. With this type of equipment, a laborer ($35.00 per hour) and a site engineer ($65.00 per hour) would be required. The total hourly cost would therefore be about $200.00 per hour. If there are two available access points per mile, it is estimated that an average of 3 boulders could be placed per hour. The average cost for placing each boulder is therefore estimated to be about $65.00.

A helicopter (with pilot) will cost about $1,200.00 per hour. With this type of equipment, two laborers (one at the stockpile and one at the placement location) and a site engineer would be required. The total hourly cost is therefore estimated to be about $1,335.00. It is estimated that an average of 15 boulders could be placed per hour. With this method, the average cost for placing each boulder is therefore estimated to be about $90.00.

The total cost for delivering a boulder to the stockpile and placing it in the river is therefore estimated to range from $100.00 to $125.00, depending on whether a hydraulic excavator or a helicopter is used. In some portions of the river, it might be feasible to operate the hydraulic excavator while other portions of the river might require the use of a helicopter.

1.6.4 Monitoring and Tracking

Monitoring methods recommended depends of what you're trying to learn. Potential questions include: did the structure stay in place?, did the treatment affect overall fish production in the system?, does the structure provide favorable fish habitat (what fish, season, and age class)? Depending on the objective, physical monitoring may include measurements of channel cross sections, longitudinal profiles, substrate characteristics, and scour at boulder locations. Photo points could be used to further document changes in physical habitat characteristics. Snorkeling could be used to document fish habitat use. Observations of fish species, size, and relative abundance could be recorded.

1.6.5 Contracting Considerations

Construction bid contracts and time and material contracts are two methods that can be used to implement boulder placement projects. Time and materials construction provides designers the ability to adjust boulder placement to field conditions found on site. Often unforeseen events create conditions where a field change would make the project better. This is a great advantage to time and materials construction.

To insure exact project costs a construction contract is another way to build a project. This type of contract places more of the cost liability on the contractor. Construction contracts require much more design work because all of the boulder placements have to be specified on paper. The disadvantage to construction contracts is there is limited ability to make a change without an adjustment in compensation. In both types of contracting, construction oversight by experienced practitioners is recommended to insure designs are being constructed properly.

1.7 Operations and Maintenance

This technique is essentially maintenance free provided that the boulders have been installed properly. Routine visits to the site should be conducted to ensure that the boulders are functioning as intended.

1.8 Examples

- St. Regis River, Montana (Lere) – example of boulders trapping sediment rather than creating scour

1.9 References

1.10 Photo and Drawing File Names

Photo – St Regis River near St. Regis, Montana
Drawing – boulder.jpeg